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Changes in the cephalopod diet of southern elephant seal females at King George Island, during El Niño-La Niña events

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Possible effects of 'El Niño' Southern Oscillation (ENSO) components 'El Niño' and 'La Niña' on populations of southern elephant seals, *Mirounga leonina*, were analysed. Changes in the cephalopod diet composition of moulting females at King George Island, Antarctic Peninsula were considered. The diet of female elephant seals sampled in 1991–1992 and 1992–1993 (El Niño years) were compared with those taken in 1995–1996 (La Niña year) at the same site and employing the same methodology. The squid *Psychroteuthis glacialis* constituted the main cephalopod prey of the seals. A reduction in the 'Index of Biomass Ingested' by female elephant seals (IBIF) of this prey species was observed in 'El Niño' years (1992, 1993) compared with the 'La Niña' year (1996). This reduction in biomass applied to all squid species in the seals' prey with the exception of *Galiteuthis glacialis*, which occurred in low numbers, but was more abundant during El Niño years than in the La Niña year.

INTRODUCTION

The life cycle of southern elephant seals comprises two periods on land, one for breeding the other for moulting. Both events are extremely exigent in terms of energy. Females have to store enough energy reserves to last the breeding period fast during which they increase the birth mass of their pups over an average of 23.7 days of lactation (Arnbom et al., 1997). Ahead of the following moulting period they have to recover, at least in part, the biomass lost during breeding to store enough reserves to cope with a second starvation period. Although in terms of energy stores required, breeding is approximately twice as expensive as the moult (Boyd et al., 1993) the feeding period (March–August) prior to breeding (Vergani, 1985; Vergani & Stanganelli, 1990; Bornemann et al., 2000) lasts three times longer than the feeding period prior to the moult (November–December).

Female elephant seals breed and moult annually at King George Island, South Shetland Islands. Breeding females arrive between 8 and 26 September and reach breeding season peak between 21 and 31 October (Vergani & Stanganelli, 1990; Vergani et al., 2001). Moulting females that had bred at King George Island as well as some from the South Georgia breeding population start arriving early December and depart from the beaches in early April (Vergani, 1985; McConnell et al., 1992; McConnell & Fedak, 1996). The group of females (3 of 12) which bred at South Georgia fed to the south-west of Adelaide Island (Antarctic Peninsula). At the time of moulting (December–January) these seals were approximately 1500–3000 km distant from South Georgia (Figure 1), and must have completed their moult on beaches in the vicinity of the Antarctic Peninsula: tagged individuals in South Georgia were found moulting at King George Island. Although there is no information on the feeding ecology of post-breeding elephant seals at King George Island most of the post-moulting females which had travelled south-west along the coast of the Antarctic Peninsula into the Bellingshausen Sea reaching the area of Alexander Island (Bornemann et al., 2000). Possible effects of 'El Niño' Southern Oscillation (ENSO) on breeding population trends (Vergani & Stanganelli, 1990) and pup weaning mass in female elephant seals have also been examined, with weaning mass higher during 'La Niña', and lower during 'El Niño', the cold and warm phases of ENSO respectively (Vergani et al., 2001).

Major effects of El Niño–La Niña anomalies on the Antarctic ecosystem may be related to the seasonal variability of the pack-ice zone. This zone is the most productive area in the Antarctic region on an annual basis (Hempel, 1985) and variation in pack ice extent may cause pronounced changes in food availability for female elephant seals. Although monthly ENSO fluctuation appears to be linked with monthly fluctuations in Western Antarctic Peninsula (WAP) sea ice extent (Smith et al., 1996), no direct evidence of changes in food availability to the female elephant seals has as yet been found in these periods.

MATERIALS AND METHODS

A way in which to explore changes in food availability is to compare biomass ingested by female elephant seals during El Niño and La Niña years. The first preliminary studies on diet were carried out at King George Island in 1991–1992 and 1992–1993 during the moulting season (Piatkowski & Vergani, 2000). A complementary study was carried out in 1995–1996 (Daneri et al., 2000). In this study we report on the cephalopod diet of moulting

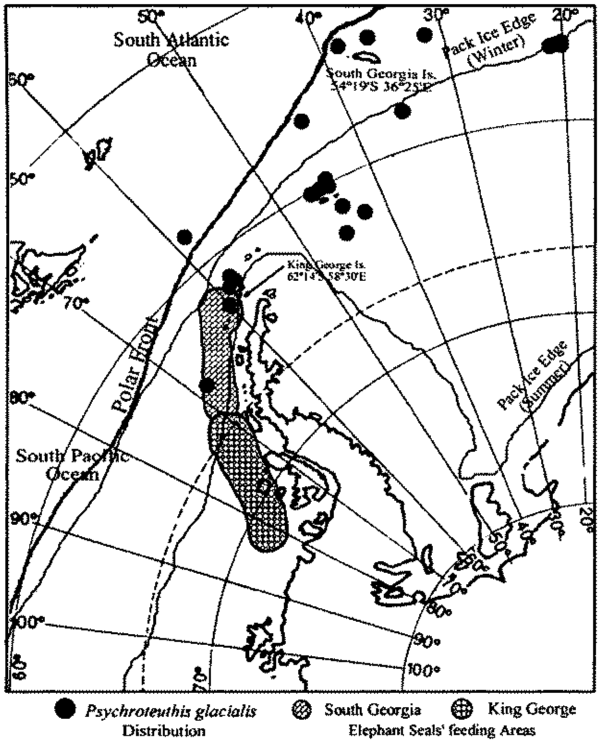

Figure 1. Geographical distribution of the squid *Psychroteuthis glacialis* according to Xavier et al. (1999) and feeding areas of female southern elephant seals (*Mirounga leonina*) according to McConnell et al. (1992), McConnell & Fedak (1996), and Bornemann et al. (2000).

female elephant seals at King George Island in 1991–1992 and 1992–1993, both El Niño years, and compared it with those taken in 1995–1996 by Daneri et al. (2000) during a La Niña year.

At Stranger Point, King George Island (62°14'S 58°30'W) stomach lavages for 13 females in 1991–1992 and 17 females in 1992–1993 were done during the moulting season following the technique developed by Antonellis et al. (1987). Females were immobilized by injection of ketamine-hydrochloride, stomach lavaged and cephalopod beaks were removed from the stomach contents and stored in 70% ethanol. Lower beaks were identified by reference collections and after Clarke (1986). Lower rostral length (LRL) was measured with a digital calliper to the nearest of 0.1 mm. Allometric equations from Clarke (1986); Gröger et al. (2000) and Piatkowski et al. (2001) were used to relate LRL to dorsal mantle length (ML, in mm) and wet mass (in g), and with 1995–1996 data of Daneri et al. (2000) who sampled 14 females using the same methodology.

A comparative 'Index of Biomass Ingested' (IBIF) (Hochberg, 1974) by female elephant seals was calculated and related to El Niño and La Niña years, respectively, with IBIF$=\Sigma$ squid biomass of each sample (B_s) divided by the total number of female elephant seals sampled (N_f).

To identify ENSO events during the study period, the index of sea surface temperature (SST) called 'Niño 3.4' for the region 5°N–5°S, 120°E–170°W was applied following Trenberth (1997). On four occasions the average of SSTs in the El Niño 3.4 index exceeded the 0.4°C threshold for more than five months, indicating the occurrence of El Niño. On three occasions the values were below 0.4°C indicating the occurrence of La Niña events.

RESULTS

Squid beak composition analysis in female seal stomach contents taken in 1992, 1993 and 1996 are shown in Table 1. The glacial squid *Psychroteuthis glacialis* was the most abundant cephalopod prey, both numerically and in terms of

Table 1. *Squid biomass ingested by female elephant seals.*

	Psychroteuthis glacialis			*Alluroteuthis antarcticus*			*Galiteuthis glacialis*		
Year	1992	1993	1996	1992	1993	1996	1992	1993	1996
N_f	13	17	14	13	17	14	13	17	14
$B_{s\ g}$	9972	7208	38969	891	294	3740	231	84	0
Mean: B_s/N_b	102.8	180.2	182.1	296.9	147.1	287.7	57.7	21.1	0
SD	82.8	221.6	133.2	217.9	120.8	171.6	20.8	21.0	0
IBIF: Bs/Nf	7.5	2.4	15.3	0.2	0.1	0.9	0.3	0.2	0
N_b	97	40	214	3	2	13	4	4	0

	Brachioteuthis sp.			*Kondakovia longimana*			*Gonatus antarcticus*		
Year	1992	1993	1996	1992	1993	1996	1992	1993	1996
N_f	13	17	14	13	17	14	13	17	14
$B_{s\ g}$	56	0	130	1578	0	1422	0	161	1643
Mean: B_s/N_b	9.4		7.2	789.2	0	203.2	0	80.3	164.3
SD	1.0		0.9	160.2	0	212.0	0	2.9	103.6
IBIF: Bs/Nf	0.5	0.0	1.3	0.2	0	0.5	0	0.1	0.7
N_b	6	0	18	2	0	7	0	2	10

N_f, number of elephant seals sampled; B_s, total Squid Biomass; N_b, number of squid beaks; IBIF, index of Biomass Ingested by Female Elephant Seals.

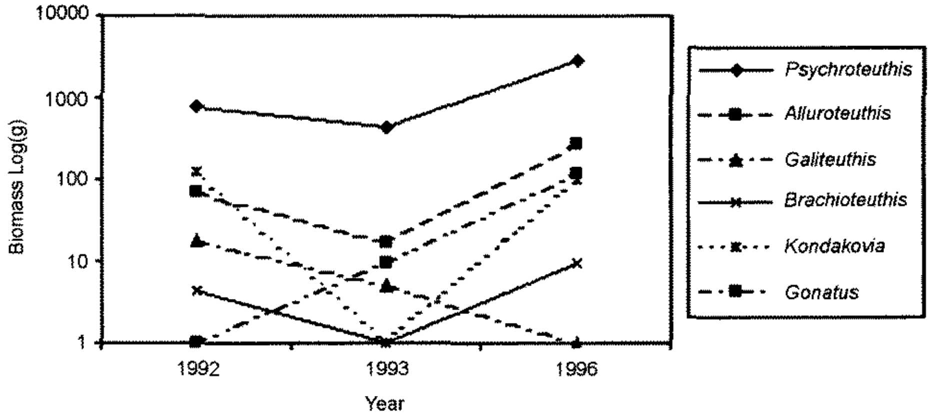

Figure 2. Index of cephalopod Biomass Ingested by Female elephant seals (IBIF) variation.

Table 2. *Variation of % biomass contribution to elephant seal diet at South Georgia (from Rodhouse et al., 1992).*

	1986	1988
Moroteuthis knipovitchi	40.3	22.7
Psychroteuthis glacialis	3.5	26.6
Kondakovia longimana	21.0	26.9

biomass. In general, a reduction in IBIF occurred during El Niño years (1992, 1993) compared with the La Niña year in 1996 (Figure 2). The reduction in IBIF was obvious for all major squid species with the exception of *Galiteuthis glacialis* which showed a reverse pattern, although the number and biomass of this squid were comparatively low.

The increase in number and biomass of *Psychroteuthis glacialis* during La Niña years and decrease during El Niño years could explain the findings of Rodhouse et al. (1992) at South Georgia. In their study stomach samples were taken in 1986 and 1988, which were El Niño and La Niña years according to Trenberth (1997). The importance of *P. glacialis* in the diet of elephant seals increased by a factor of seven in the La Niña year at South Georgia (Table 2). Vergani & Stanganelli (1990) also suggested that ENSO effects on top predators were seen simultaneously at South Georgia and King George Island during the 1982–1983 El Niño events. This observation seems to be supported by the fact that a proportion of South Georgia female southern elephant seals migrated to the WAP region to feed (McConnell et al., 1992; McConnell & Fedak, 1996), a known feeding area for females from King George Island (Bornemann et al., 2000).

DISCUSSION

Although squid play a key role in the marine ecosystem of the Southern Ocean (Ainley & DeMaster, 1990) the distribution of Antarctic cephalopods is poorly known, due to, e.g. their fast swimming, which may make them difficult to sample with conventional research trawls (Wormuth & Roper, 1983). This is in contrast to Antarctic top predators such as elephant seals which seem to prey effectively on cephalopods in order to maintain their high energy demands.

However, to study squid distribution and abundance by sampling their beaks from elephant seal stomach contents introduces a serious bias. Cephalopod beaks may be retained longer in the rugae of the stomach than fish remains (Bigg & Fawcett, 1985) thus overestimating the general importance of cephalopods in the diet. Although the mean retention time of digesta in southern elephant seals is estimated to be about 13 hours (Krockenberger & Bryden, 1994) there are no precise data on the retention time of cephalopod beaks in the stomachs, and thus what period of foraging they represent (McConnell & Fedak, 1996). At South Georgia the retention time was estimated to be 2–3 days, and with an average travel speed of 61 km/day during the post moult/breeding migration of female elephant seals; the stomach samples represented a feeding area located about 122–183 km from the island (McConnell & Fedak, 1996).

On the other hand, given that the feeding grounds of adult female elephant seals from King George Island are closely associated with the edge of the pack ice zone Bornemann et al. (2000) which apparently coincides with the distribution of the major cephalopod prey, *Psychroteuthis glacialis* (Xavier et al., 1999) (Figure 1) a scenario of how ENSO can effect the feeding pattern of the seals can be explained as follows: during El Niño years when the pack ice has a minimum coverage, female seals have to travel longer distances during the initial transit phase from their breeding places in order to reach feeding areas. Hence, in subsequent stomach analyses the process of digestion is more advanced due to the long return journey, resulting in lesser numbers of squid beaks. During La Niña years the pack ice extension is larger, the seals do not migrate long distances to feeding grounds, and the stage of digestion is not so much advanced. this would conceivably result in higher abundance of squid beaks in stomach contents. This underlines that changes in numbers of squid beaks in stomach contents do not necessarily reflect fluctuations in squid availability in the field, although in the Patagonian Shelf area correlations between sea surface temperature (SST) and squid abundance reflected an increase of squid biomass at their spawning sites, with lower SST associated with higher catches of *Illex argentinus* (Waluda et al., 2000). Therefore, the finding that elephant seal weaning mass is higher during La Niña years (Vergani et al., 2001) could suggest that *Psychroteuthis glacialis* availability to the female elephant seals had increased concomitant with lower SST during La Niña years.

Bornemann et al. (2000) postulated that the main prey item of southern elephant seals from King George Island would be *Pleuragramma antarcticum* and Brown et al. (1999) suggested that elephant seals of South Georgia probably fed on larger nototheniids and myctophid fish. However, the rapid changes in weaning mass associated with La Niña and El Niño events (Vergani et al., 2001) seem to indicate that elephant seals depend on species such as squid with short life spans rather than on long lived species such as the pelagic Antarctic fish, *P. antarcticum* where the effect of anomalies like ENSO probably would be seen later in the weakness of recruitment and not immediately.

An integrated study of pup weaning mass, stomach content analysis and sea ice density fluctuation during La Niña/El Niño events would be necessary to corroborate this hypothesis, but the model represents a first attempt to study the effect of ENSO on a top predator of the Antarctic ecosystem.

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